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Spatial variability in terrestrial fauna surveys; a case study from the goldfields of Western Australia

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Abstract

Although spatial variability in fauna assemblages has been discussed in the literature for many decades, terrestrial fauna surveys undertaken to support environmental impact assessments (EIAs) in Western Australia (WA) rarely adequately address this issue when undertaking surveys of the terrestrial vertebrate ecosystems. The specific objective of this investigation was to describe the spatial variability in the trapped terrestrial vertebrate fauna for five vegetation assemblages in the semi-arid northern goldfields region of WA. The trapped terrestrial vertebrate assemblage differed significantly among replicate sites in both the composition and relative abundance in each of the five habitats. A high proportion of species trapped were singletons and doubletons, and many species demonstrated a patchy distribution within habitats. Both of these parameters provide a strong case for addressing spatial diversity in terrestrial fauna surveys undertaken to support EIAs.

Key words: fauna survey, spatial variability, Western Australia, reptiles, mammals, rarity, environmental impact assessment, EIA

Introduction

The Western Australian (WA) Environmental Protection Authority (EPA) in its Position Statement No 3 Terrestrial Biological Surveys as an Element of Biodiversity Protection (2002) and supporting Guidance Statement No 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (2004) indicated that it requires a proponent of development to undertake appropriate terrestrial fauna surveys to provide sufficient information to address both biodiversity conservation and ecological function values.

To adequately assess potential impacts on ecosystems and ecosystem function, we believe it is necessary that a near complete list of the terrestrial species and their relative abundance is provided for each of the major habitats (see Kodric-Brown & Brown 1993). Although spatial variability and spatial distributions within and among species is an obvious issue that should be addressed in planning terrestrial fauna surveys (see Gaston & Blackburn 2000; Hanski 1999, and references therein), we were unable to find any recent terrestrial fauna surveys undertaken to support EIAs that adequately addressed this issue. If there is high variability in species spatial occupancy, then a single survey site might be inadequate to represent the fauna assemblage in a habitat (Greenwood & Robinson 2006). Greenwood and Robinson (2006) indicated that a single sampling unit can only provide an imprecise estimate for the whole study population, so it is necessary to increase the sampling units to increase precision and representativeness. Typically, terrestrial fauna surveys undertaken for the purpose of preparing an EIA in WA use one or two sampling units in each habitat type (*e.g.* see Bamford Consulting Ecologists 2007; Biota Environmental Sciences 2005a, b, c; Ecologia Environment 2004, 2006; Western Wildlife 2006; Outback Ecology Services 2006).

As a first step in addressing this issue, we set out here to describe the spatial variability in the trapped terrestrial vertebrate fauna in five vegetation assemblages in the semi-arid northern goldfields region of WA. The presence of some rare and conservation significant vertebrate fauna can be assessed as part of a generic terrestrial vertebrate fauna surveys. Other rare and conservation significant species require focussed species-specific searches. This paper only addresses the fauna component of developing an appreciation of the ecological functions of a particular habitat and where generic trapping surveys are expected to identify the presence and abundance of rare and conservation significant species.

An assumption underlying this analysis is that vertebrate fauna assemblages will vary with vegetation assemblages (Thompson *et al.* 2003), which in turn are influenced by physical attributes such as soils, topography and rainfall.

Methods

Study sites

Five distinctly different vegetation assemblages were selected in an area about 30 km south of Wiluna, Western Australia (26° 50'S, 120° 07'E). These were: chenopod shrublands on a flat plain (chenopod); red sand-ridges and swales mostly vegetated with spinifex and low scattered shrubs (sand dune); mulga woodland with an understorey of spinifex (mulga spinifex); mulga woodland without an understorey of spinifex (mulga); and sand plains vegetated with spinifex and scattered shrubs (spinifex sand plain). As the terrestrial fauna assemblage was likely to be different on the sand ridges and adjacent swales, all trapping lines in this habitat were run off the dune onto the swale to ensure trapped fauna would be directly comparable among sites.

The trapping program for each of these five vegetation assemblages was designed to address both temporal and spatial variability in the fauna assemblage and to enable a direct comparison to be made among sites in each vegetation assemblage. For each vegetation assemblage, four 'replicate' sites were selected. The four sites in each vegetation assemblage were far enough apart so as to limit movement of individuals among sites (*i.e.* they were independent, > 500 m apart; Table 1).

Each survey site contained four trap lines. Each trap line contained three 20 L PVC buckets, three 150 mm by 500 mm deep PVC pipes as pit-traps and three pairs of funnel traps evenly spaced along a 30 m fly-wire drift fence that was approximately 250 mm high. In addition, three Elliott traps were set adjacent to each drift fence and one wire cage trap was placed between each pair of drift fences and these traps were baited with rolled oats, peanut butter and sardines.

All pit-traps were dug in during July 2006 to minimise 'digging-in' effects. Digging-in effects occur when particular species are attracted to freshly turned soil in search of prey (*e.g. Varanus gouldi, V. eremius*) and are caught as a result, potentially biasing the catch data. There were two seven day survey periods – 17–23 October 2006, and 11–17 January 2007 to ensure that temporal variation in small vertebrate activity patterns was adequately addressed (see Thompson & Thompson 2005). All traps remained open for a period of seven nights during each survey period. The trapping effort for each of the 20 sites was designed to exceed that which would normally be used by environmental consultants undertaking terrestrial fauna surveys in a vegetation assemblage for the purpose of preparing an EIA (see Biota Environmental Sciences 2005a, b; Ecologia Environmental Consultants 2004, 2006; Western Wildlife 2006; Outback Ecology Services 2006).

All mammals, reptiles and amphibians caught in traps were identified and recorded. Most individuals were released near their point of capture, but away from the traps to minimise immediate recapture. A small number of individuals were vouchered with the Western Australian Museum. Only mammals and reptiles caught are included in this analysis, as the activity pattern of arid-adapted frogs in this area is heavily influenced by patterns of rainfall, and their inclusion in the analysis was likely to distort the results. Incidental observations were not included in the dataset. All captures were marked so that recaptured individuals could be identified. As the rate of recaptures was less than 1% and as most environmental consultants do not record recaptures, all captures were included in the analysis.

Data analysis

Trapped assemblage structure can be measured in numerous ways (Hayek & Buzas 1997; Magurran 2004). The four most common attributes are species richness, evenness, relative abundance and a composite measure of diversity. These metrics are interrelated and there are numerous analytical tools available to quantify differences among assemblages for each of these attributes (Magurran 2004).

Species richness and relative abundance

The actual number of species caught at each site was one measure of species richness and is directly related to the trapping effort and number of individuals caught. Had the trapping effort been extended and more individuals caught it is highly probable that the number of species caught would increase (Colwell & Coddington 1994; Magurran 2004). Colwell and Coddington (1994) reported Chao 2 and Jackknife 2 estimates of species richness provided remarkably accurate estimates for small samples. Chazdon *et al.* (1998) suggested that incidence-based coverage estimator (ICE) and Chao 2 performed well with small samples. Based on these assessments, Chao 2 was used to estimate species richness for each of the sites sampled and was calculated using Colwell's EstimateS software (http://viceroy.eeb.uconn.edu/estimates).

ANOVA (using StatistiXL, V1.6, http: www.statistixl.com) was used to determine significant differences among the number of individuals and the number of species caught in each vegetation assemblage, with the number of individuals and species at each of the four sites in each vegetation assemblage providing the variance. A repeated measures ANOVA was used to test significant difference among the number of individuals caught in each of the nine vertebrate families, with the number of individuals caught at each of the four sites in each vegetation assemblage providing the variance. Sites

Table 1

Location of all trapping sites (UTM Datum WGS 84)

Site #	Chenopod	Sand dunes	Mulga spinifex	Mulga	Spinifex sand plain
1	51 237168E 7025570N	51 243372E 7025229N	51 243063E 7018666N	51 243111E 7016356N	51 241785E 7018871N
2	51 238085E 7025392N	51 23999E1 7027902N	51 243112E 7020014N	51 238889E 7020384N	51 242799E 7017924N
3	51 238454E 7025665N	51 239793E 7027753N	51 243140E 7020828N	51 240503E 7020728N	51 242813E 7017639N
4	51 238672E 7025598N	51 238261E 7029074N	51 243604E 7022375N	51 245212E 7022402N	51 242143E 7018147N

were treated as repeats in this analysis. This was not a powerful analytical tool because the sample sizes for each vegetation assemblage were small. Large differences would therefore be required for a statistical difference to be detected.

Evenness

Magurran (2004) supported Smith and Wilson's (1996) assessment that their measure of evenness (E_{var}) was a satisfactory overall measure. E_{var} was calculated for each of the trapped assemblages using Species, Diversity and Richness software (Pisces Conservation Ltd, V4.0).

Diversity

Log series diversity (Fisher's alpha) was used to measure diversity because of its good discriminating ability and low sensitivity to sample size (Kempton & Taylor 1974; Hayek and Buzas 1997; Magurran 1988). Log series diversity was calculated using Species, Diversity and Richness software (Pisces Conservation Ltd, V4.0). To examine differences in diversity among sampled sites for each vegetation assemblage we adopted Magurran's (2004) advice and compared the slopes of rank/abundance plots (Whittaker plots). When the relative abundance of each species is log-transformed (Y axis; $\log_{10}$) and plotted against the ranking of species from highest to lowest, the downward sloping line of best fit for undisturbed habitats should approach linearity (Magurran 2004). Presuming these lines are linear, a comparison of the exponents of the regression lines provides a tool for statistically examining differences among diversity for the trapped assemblage for each site in each vegetation assemblage. For our data, we had an unusually high number of singletons in many of the datasets, which reduces the slope of the regression line (and perhaps the assumption of linearity). Singletons can represent individuals that are either rare or vagrants, are difficult to catch using the trapping protocols used or have temporarily moved into a habitat in which they would not normally be found. To address this problem we repeated the comparison of regression line exponents excluding singletons from the dataset, and report the results from both analyses.

Similarity

Our results indicated significant differences among the trapped assemblages between and within vegetation assemblages, so based on this information we wished to indicate the extent to which they were similar. We used the Morisita-Horn index to compare similarity between various combinations of sites and a principle component analysis (PCA) to show affinity among all sites. The quantitative Morisita-Horn similarity index was selected because it is not strongly influenced by either species richness or sample size (Wolda 1981) and was recommended by Magurran (2004); however, it should be noted that it is sensitive to the abundance of the most abundant species. A PCA (using StatistiXL, V1.6, http: www.statistixl.com) was used to provide a multiple dimensional grouping of species.

Results

The local weather conditions for each of the survey periods were typical for October and January for this area. A total of 2783 reptiles and mammals from 61 species were trapped during the October and January surveys (Table 2). There was a significant difference in the number of individuals caught at each of the sites among vegetation assemblages (ANOVA, $F_{4, 15} = 4.69$, $P = 0.012$) but no significant difference in the number of species caught (ANOVA, $F_{4, 15} = 0.93$, $P = 0.474$). Chao's estimate of species richness varied appreciably among sites for each vegetation assemblage (Table 3). Estimated mean species richness (Chao 2) for at least one site in each vegetation assemblage fell outside the 95% CI range for another site in all vegetation assemblages.

The total number of individuals caught in each of the five vegetation assemblages differed and probably reflected the abundance of small vertebrates in each of the vegetation assemblages. There was also a significant difference in the number of individuals caught in the families at each site (ANOVA, $F_{3,12} = 4.0$, $P = 0.014$) and there was no interaction effect among vegetation assemblages ($F_{4,40} = 0.372$, $P = 0.83$).

The species accumulation curve for the entire data set indicates that a total of 65 species could be trapped at all sites (*e.g.* the asymptote). In addition to the trapping program that caught 61 species, *Nephrurus milii*, *Brachyurophis approximans*, *Parasuta monachus*, *Pseudechis butleri* and *Suta fasciata* were caught while spotlighting in the five vegetation assemblages but were not caught in traps. All these species have previously been caught in either pit- or funnel traps at other locations.

Of the 61 species caught at all sites, nine were singletons (only caught once) and two were doubletons, indicating that there was a high proportion (14.8% and 3.3% respectively; Table 3) of species that were rarely caught in traps and would reduce similarity scores calculated to compare vertebrate fauna assemblages among vegetation assemblages (Table 4). Because sample sizes were appreciably smaller for sites than the combine sites for each vegetation assemblage, there were many more singletons and doubletons in the site catch data.

The shape of species accumulation curves for individual sites differed within vegetation assemblages. Thompson and Withers (2003) explained how the shape of the species accumulation curve could be used to understand the assemblage structure, as it is influenced by both relative abundance and species richness. Sites with a high proportion of rare species and a few abundant species have a species accumulation curve with a low 'shoulder' (inflection point on the ordinate axis) and a long upward slope to the asymptote, whereas sites with a high proportion of relatively abundant species have a steeply rising initial slope to the species accumulation curve and plateaux early. An inspection of the species accumulation curves in Figure 1 indicates appreciable difference among sites for each vegetation assemblage in vertebrate assemblage structure.

Fisher's alpha diversity score for the combined data for all 20 sites was 11.03. As expected, diversity was lower in each of the 20 survey sites (Table 3) with the mulga spinifex habitat type having the lowest variability in diversity, as measured by the standard deviation (0.76) for its four sites, followed by the spinifex sand plain habitat (0.79), the sand dune habitat (1.31), the mulga

Table 2

Vertebrates trapped during the October 2006 and January 2007 in 20 sites, four of which were in each of five vegetation assemblages.

Species	Sand Dune					Mulga					Mulga Spinifex					Chenopod					Spinifex Sand Plain					Total all sites
	Site 1	Site 2	Site 3	Site 4	Total	Site 1	Site 2	Site 3	Site 4	Total	Site 1	Site 2	Site 3	Site 4	Total	Site 1	Site 2	Site 3	Site 4	Total	Site 1	Site 2	Site 3	Site 4	Total	
Mammals																										
Dasyuridae																										
Antechinomys laniger																								1	1	1
Dasycercus cristicauda																					4	2	1		7	7
Ningaui ridei	4	4	3	14	25			2		2	13	4	15		32		2			2	16	11	21	26	74	135
Sminthopsis macroura	1				1	3	6			9							3	1	1	5						15
Sminthopsis hirtipes			1		1																					1
Sminthopsis ooldea	2	2	2	2	8	11	2	1	5	19	2	4	11	3	20		5	3	4	12	1		2	3	6	65
Muridae																										
Mus musculus	3	3	4	14	24	1				1		1	1		2	5	2	4	5	16		1	1	3	5	48
Notomys alexis	20	39	13	39	111	13	15	26	29	83	26	23	14	7	70	4	10	5	17	36	5	17	19	10	51	351
Pseudomys desertor	1	3	1	5	10	2	2	2	3	9	5	4	3	1	13	4	3	1	6	14	10	3	2	3	18	64
Pseudomys hermannsburgensis	12	5	5	13	35	9	2	12	5	28	5	1	13	5	24	8	7	9	12	36	2	9	20	8	39	162
Reptiles																										
Gekkonidae																										
Diplodactylus conspicillatus			5		5	8	4	9	9	30	8			21	29	4				4	1	3	29	10	43	111
Diplodactylus pulcher						1	5		1	7						1				1						8
Gehyra variegata	2	1	6		9		1		1	2	4		1		5		1		1	2		1		1	2	20
Heteronotia binoei																							1		1	1
Lucasium squarrosum							10	2	2	14							1			1						15
Nephrurus laevissimus	37	14	28	15	94																					94
Nephrurus vertebralis	2	1		1	4			1	2	3			1		1			1	2	3					11
Rhynchoedura ornata	1	3	15	1	20	8		7	14	29		5			5	12	13	32	26	83			8	2	10	147
Strophurus elderi				8	8			2	1	3	9	1	9		19						16	22	8	18	64	94
Strophurus strophurus				1	1													2	1	3						4
Strophurus wellingtonae						7		1	3	11		1	2	1	4											15
Pygopodidae																										
Aprasia picturata													1		1											1
Delma butleri	1			6	7							1			1						4			2	6	14
Delma nasuta				3	3									1	1		1			1	1				1	6
Lialis burtonis		1		4	5						2				2		3		1	4		1	1	1	3	14
Pygopus nigriceps	1				1		2	2		4	1	1	1	2	5			2	1	3						13
Scincidae																										
Ctenotus ariadnae											7	7	7	7	28	1				1	14	10	7	13	44	73
Ctenotus grandis											10		7	1	18						5	10	2	8	25	43
Ctenotus helenae	2	3	8	26	39	2		17	2	21	32	11	56	12	111	14	3		1	18	18	29	17	53	117	306
Ctenotus leonhardii	8	2	13	7	30	20		25	14	59	19	47	20	25	111	32	20	21	14	87		3	17	6	26	313
Ctenotus pantherinus						3		5	1	9	47	2	54	20	123						19	39	30	72	160	292
Ctenotus schomburgkii						7	2	6	7	22		1			1	3			1	4						27

Egernia depressa		1			1	3			1	4														5
Egernia inornata												8			8	6				6			1	1	15
Eremiascincus richardsonii																			1	1					1
Lerista desertorum	2			1	3			1		1		10	7	2	19	2		4	1	7	1			1	31
Lerista rhodonoides									1	1			1		1										2
Menetia greyii		2	1		3		2		2	4	3	4	4	4	15	6	2	2	3	13		1	1	2	37
Tiliqua multifasciata											1				1						3			3	4
Agamidae																									
Caimanops amphiboluroides						1	1			2															2
Ctenophorus isolepis	6		1		7				2	2	9	4		1	14						8	6	15	9	38	61
Ctenophorus nuchalis	4		1		5												16	1		17				1	1	23
Ctenophorus reticulatus							1		2	3															3
Ctenophorus salinarum	1				1																				1
Ctenophorus scutulatus				2	2		1	1	12	14															16
Lophagnathus longirostris			1		1																				1
Moloch horridus		1			1																				1
Pogona minor	1				1									1	1			1	1	2	1		1	1	3	7
Varanidae																									
Varanus brevicauda			1		1								1	1	2						3	5	1	6	15	18
Varanus caudolineatus						1	2	1	1	5							1			1						6
Varanus eremius											2				2						1	1	4	1	7	9
Varanus gouldii	1	1			2				1	1		2	1		3											6
Varanus panoptes	3	1	2	4	10		1		1	2	2		1	1	4	2		3	1	6		1			1	23
Varanus tristis								1		1																1
Elapidae																									
Brachyurophis semifasciata	1				1			1		1	1				1			3		3				2	2	8
Furina ornata	2			1	3																		1		1	4
Pseudonaja modesta								2	1	3													1		1	4
Pseudonaja nuchalis			1	2	3	1				1								2	1	3						7
Simoselaps bertholdi		1			1													2	2	4			1		1	6
Typhlopidae																									
Ramphotyphlops hamatus	1				1							1		1	2				4	4						7
Ramphotphylops waitii				1	1									1	1		1			1						3
Grand Total	119	88	112	170	489	101	59	127	123	410	208	143	231	118	700	104	94	99	107	404	133	175	211	261	780	2783
Total # Species	25	19	20	22	40	18	17	22	26	35	21	22	23	21	37	15	18	19	23	34	20	20	25	25	35	61
# Mammal species	7	6	7	6		6	5	5	4		5	6	6	4		4	7	6	6		6	6	7	7		10
# Reptile species	18	13	13	16		12	12	17	22		16	16	17	17		11	11	13	17		14	14	18	18		51
# Dasyuridae	5	4	3	14		3	6	2	0		13	4	15	0		0	5	1	1		20	13	22	27		158
# Muridae	38	52	26	73		36	21	41	42		38	33	42	16		21	27	22	44		18	30	44	27		691
# Gekkonidae	42	19	54	26		24	20	22	33		21	7	13	22		17	15	35	30		17	26	46	31		520
# Pygopodidae	2	1	0	13		0	2	2	0		3	2	2	3		0	4	2	2		5	1	1	3		48
# Scincidae	12	8	22	34		35	4	54	28		119	90	156	71		64	25	27	21		60	92	74	153		1149
# Agamidae	12	1	3	2		1	3	1	16		9	4	0	2		0	16	2	1		9	6	16	11		115
# Varanidae	4	2	3	4		1	3	2	3		4	2	3	2		2	1	3	1		4	7	5	7		63
# Elapidae	3	1	1	3		1	0	3	1		1	0	0	0		0	0	7	3		0	0	3	2		29
# Typhlopidae	1	0	0	1		0	0	0	0		0	1	0	2		0	1	0	4		0	0	0	0		10
Fisher's Alpha	9.65	7.45	7.09	6.73		6.37	8.00	7.68	10.07		5.82	7.26	6.35	7.43		4.81	6.61	6.99	9.00		6.53	5.82	7.38	6.80		11.03

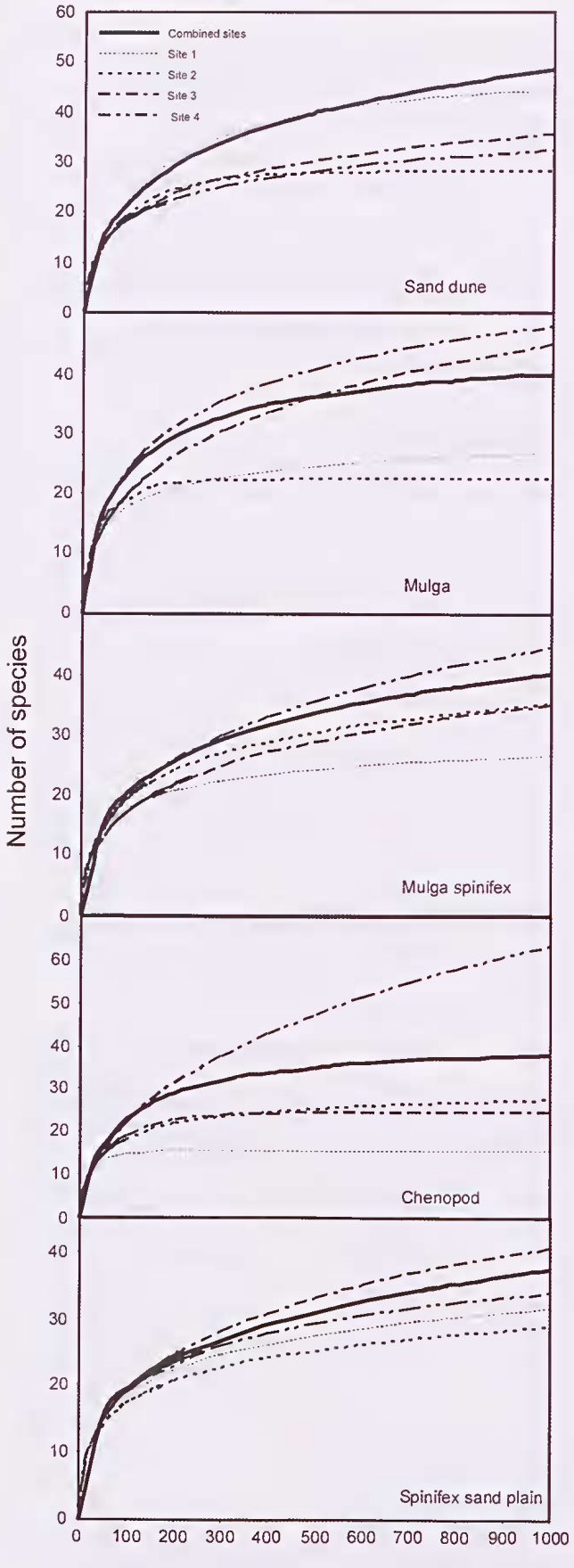

Figure 1. Species accumulation curves for each site and the combined sites for each vegetation assemblage.

habitat (1.53) and with the highest being the chenopod habitat (1.72). Alpha diversity scores varied among sites for each vegetation assemblage (Table 3).

The slope of regression lines for the Whittaker plots differed significantly for the sand dune ($F_{3,75}$ = 4.51, P < 0.01), mulga ($F_{3,75}$ = 4.72, P < 0.01) and the spinifex sand plain ($F_{3,81}$ = 3.04, P < 0.01) habitats, but did not differ for the chenopod ($F_{3,67}$ = 2.41, P = 0.07) and mulga spinifex ($F_{3,79}$ = 1.02, P = 0.39) sites. However, when singletons were removed, only the slopes for the sites in the mulga spinifex habitat ($F_{3,49}$ = 4.76, P < 0.01) differed significantly [chenopod ($F_{3,43}$ = 1.58, P = 0.21), sand dune ($F_{3,46}$ = 0.86, P = 0.47), mulga ($F_{3,47}$ = 1.70, P = 0.18) and spinifex sand plain ($F_{3,53}$ = 1.16, P = 0.33)]. This difference in the regression line slopes with and without singletons in the data sets indicates the appreciable influence that singletons were having on the assemblage structure. Therefore it was anticipated that evenness values would differ among sites in each vegetation assemblage (Table 3) and for each vegetation assemblage at least one mean value fell outside the 95% confidence limits for another site in that vegetation assemblage.

The proportion of shared species among the five different vegetation assemblages varied from 54 to 80% (Table 4). The most dissimilar fauna assemblages measured using the Morisita-Horn similarity index were the chenopod and the spinifex sand plain habitats (0.28), and the most similar were the mulga spinifex and spinifex sand plain (0.87). The mean Morisita-Horn similarity score among fauna assemblages (0.56) for the five vegetation assemblages was lower than for each of the sites for each vegetation assemblage (0.76 for chenopod, 0.71 for sand dune, 0.68 for mulga spinifex, 0.89 for mulga and 0.81 for spinifex sand plain). Variability in the Morisita-Horn scores among sites for each vegetation assemblage, as measured by the standard deviation, was lowest for the chenopod habitat (0.072), followed by the spinifex sand plain habitat (0.093), the sand dune habitat (0.097), the mulga habitat (0.158) and highest among the mulga spinifex sites (0.165).

Eigenvalues for PCA 1 and 2 were 10.4 and 7.2 respectively, and accounted for 17.0 and 11.9% of total variance. The PCA separated the mulga spinifex, spinifex sand plain and mulga habitats on the first PCA (Figure 2), but there was overlap between the mulga and mulga spinifex with chenopod and sand dune sites. The sand dune and chenopod habitats were separated from the other three vegetation assemblages on PCA 2, but there was an overlap between the fauna assemblages in each of these vegetation assemblages. Only the spinifex sand plain sites clustered closely, there was an obvious 'outlier' for the mulga and sand dune sites, and some distance between fauna assemblages in the chenopod and mulga spinifex habitats. The fauna assemblage at one mulga spinifex habitat was closer to the spinifex sand plain sites, and the fauna assemblage at one mulga site was closer to that in a mulga spinifex assemblage than other sites within its vegetation assemblage.

Table 3

Chao 2 estimate of species richness, alpha diversity scores, and the number of singletons and doubletons for all sites and vegetation assemblages

Habitat type	Site	Trapped species richness	Species richness – Chao 2 (lower and upper 95% CI)	Alpha diversity	Evenness – E_{var} (lower and upper 95% CI)	Singletons (n/%)	Doubletons (n/%)
Mulga	All sites	35	38.25 (35.66 – 52.75)	9.16	0.35 (0.32 – 0.46)	7 (20.0)	5 (14.3)
	Site 1	18	20.32 (18.34 – 33.96)	6.37	0.50 (0.45 – 0.67)	5 (27.8)	2 (11.1)
	Site 2	17	18.16 (17.15 – 26.01)	8.00	0.63 (0.50 – 0.73)	5 (29.4)	7 (41.2)
	Site 3	22	25.57 (23.22 – 47.39)	7.68	0.43 (0.38 – 0.58)	8 (36.4)	6 (27.3)
	Site 4	26	31.39 (27.39 – 51.59)	10.07	0.49 (0.42 – 0.58)	10 (38.5)	6 (23.1)
Mulga spinifex	All sites	37	47.21 (39.53 – 78.19)	8.34	0.25 (0.24 – 0.33)	9 (24.3)	4 (10.8)
	Site 1	21	22.11(21.13 – 30.79)	5.82	0.42 (0.36 – 0.54)	3 (14.3)	4 (19.1)
	Site 2	22	30.67 (23.79 – 63.98)	7.26	0.43 (0.39 – 0.56)	8 (36.4)	2 (9.1)
	Site 3	23	34.14 (25.46 – 73.56)	6.35	0.32 (0.03 – 0.45)	9 (39.1)	1 (4.4)
	Site 4	21	34.93 (24.24 – 80.88)	7.43	0.41 (0.37 – 0.53)	10 (47.6)	2 (9.5)
Chenopod	All sites	34	38.88 (34.92 – 59.85)	8.86	0.36 ((0.32 – 0.45)	7 (20.6)	2 (5.9)
	Site 1	15	15.31 (15.02 – 20.64)	4.81	0.55 (0.44 – 0.70)	2 (13.3)	2 (13.3)
	Site 2	18	19.55 (18.21 – 29.30)	6.61	0.51 (0.43 – 0.65)	5 (27.8)	3 (16.7)
	Site 3	19	21.32 (19.37 – 33.38)	6.99	0.52 (0.41 – 0.60)	5 (26.3)	5 (26.3)
	Site 4	23	59.21 (32.35 – 163.24)	9.00	0.46 (0.40 – 0.62)	12 (52.2)	2 (8.7)
Sand dune	All sites	40	68.17 (44.65 – 144.65)	10.32	0.31 ((o,29 – 0.39)	14 (35.0)	2 (5.0)
	Site 1	25	31.38 (26.57 – 50.09)	9.65	0.50 (0.41 – 0.57)	10 (40.0)	6 (24.0)
	Site 2	19	24.20 (20.06 – 44.42)	7.45	0.52 (0.42 – 0.59)	8 (42.1)	3 (15.8)
	Site 3	20	28.67 (21.79 – 61.98)	7.09	0.44 (0.41 – 0.59)	8 (40.0)	2 (10.0)
	Site 4	22	28.50 (23.24 – 56.140	6.73	0.41 (0.37 – 0.56)	6 (27.3)	3 (13.6)
Spinifex sand plain	All sites	35	43.36 (36.97 – 70.54)	7.54	0.23 (0.22 – 0.31)	10 (28.6)	3 (8.6)
	Site 1	20	23.48 (20.59 – 40.65)	6.53	0.45 (0.45 – 0.62)	6 (30.0)	1 (5.0)
	Site 2	20	26.96 (21.22 – 59.70)	5.82	0.38 (0.34 – 0.53)	6 (30.0)	1 (5.0)
	Site 3	25	35.45 (27.45 – 69.55)	7.38	0.33 (0.32 – 0.45)	10 (40.0)	3 (12.0)
	Site 4	25	28.90 (25.73 – 45.95)	6.80	0.35 (0.32 – 0.45)	7 (28.0)	3 (12.0)
All sites				11.03		9 (14.8)	2 (3.3)

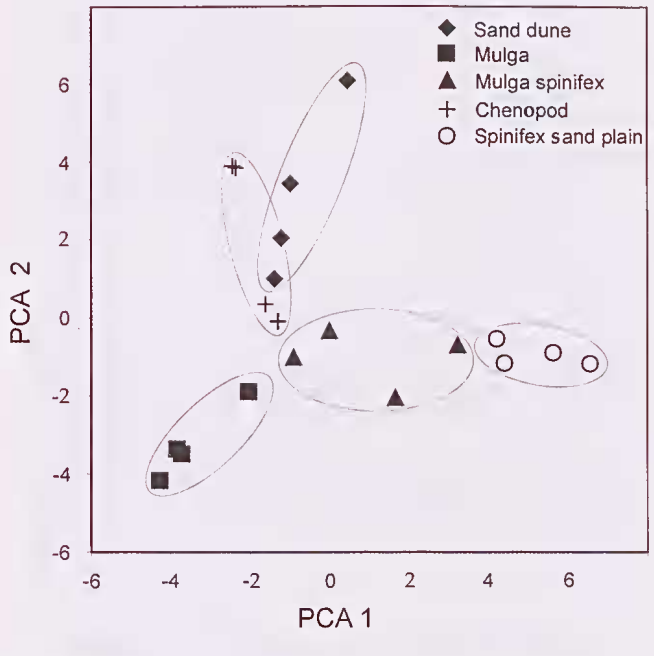

Figure 2. PCA 1 and 2 of the trapped fauna assemblage for all 20 survey sites.

Discussion

Habitat generalists and specialists

Trapped fauna assemblages differed among sites for each vegetation assemblage. Within any fauna assemblage, species sit on a continuum from those that are habitat generalists to those that are habitat specialists. Habitat generalists are those species that are quite plastic in their habitat requirements and are found in a diverse range of habitat types, whereas habitat specialists have specific habitat requirements, often with limited tolerances. Pianka (1969; 1972) and Pianka & Pianka (1976) were one of the first to categorise Australian arid and semi-arid reptiles into habitat generalists and specialists. For example, Pianka (1969) categorised arid and semi-arid Western Australian reptile species into four groups based on habitat preferences: ubiquitous, spinifex, mulga and sand ridges. It was therefore expected that some species would be common across all five vegetation assemblages and others would be restricted to one or two vegetation assemblages. In addition, some species can be evenly distributed over a large section of suitable habitat, with minor variation in relative abundance from one site to the next, whereas the distribution of other species can be very patchy, with relatively high densities in some areas and being absent in many others, although the entire area offers suitable habitat (Hanski 1999). Hanski (1999) suggested that species that are locally abundant, occur in relatively

Table 4

Similarity scores for captured fauna assemblages among vegetation assemblages and among survey sites in each habitat type (numbers in parenthesis are the recorded species richness for that habitat type)

		Shared species observed	Morisita-Horn Similarity Index
Mulga (35)	Mulga spinifex (37)	24	0.66
	Chenopod (34)	23	0.75
	Sand dune (40)	24	0.69
	Spinifex sand plain (35)	19	0.43
Mulga spinifex (37)	Chenopod (34)	25	0.54
	Sand dune (40)	27	0.49
	Spinifex sand plain (35)	28	0.87
Chenopod (34)	Sand dune (40)	27	0.50
	Spinifex sand plain (35)	22	0.28
Sand dune (40)	Spinifex sand plain (35)	25	0.39
Mulga			
Site 1 (18)	Site 2 (17)	10	0.46
	Site 3 (22)	12	0.83
	Site 4 (26)	14	0.80
Site 2 (17)	Site 3 (22)	10	0.54
	Site 4 (26)	14	0.67
Site 3 (22)	Site 4 (26)	17	0.82
Mulga spinifex			
Site 1 (21)	Site 2 (22)	13	0.53
	Site 3 (23)	15	0.92
	Site 4 (21)	14	0.77
Site 2 (22)	Site 3 (23)	16	0.46
	Site 4 (21)	14	0.68
Site 3 (23)	Site 4 (21)	15	0.70
Chenopod			
Site 1 (15)	Site 2 (18)	8	0.74
	Site 3 (19)	9	0.74
	Site 4 (23)	11	0.67
Site 2 (18)	Site 3 (19)	10	0.75
	Site 4 (23)	12	0.76
Site 3 (19)	Site 4 (23)	17	0.89
Sand dune			
Site 1 (25)	Site 2 (19)	14	0.71
	Site 3 (20)	14	0.86
	Site 4 (22)	15	0.66
Site 2 (19)	Site 3 (20)	13	0.60
	Site 4 (22)	13	0.78
Site 3 (20)	Site 4 (22)	12	0.64
Spinifex sand plain			
Site 1 (20)	Site 2 (20)	14	0.88
	Site 3 (25)	16	0.69
	Site 4 (25)	16	0.84
Site 2 (20)	Site 3 (25)	18	0.76
	Site 4 (25)	17	0.94
Site 3 (25)	Site 4 (25)	19	0.75

unfragmented habitats and are predisposed to high mobility will have few empty areas in suitable habitat. In contrast, species with low densities, occupying highly fragmented habitats and with a low predisposition to migration will have lots of empty areas in suitable habitat. These latter species can also have a wide geographic distribution but are scarce everywhere (*e.g. Antechinomys laniger*). It is these latter species that are likely to be missed in surveys that catch few individuals or are undertaken at a few sites. These species are described as scarce and patchy.

For the five vegetation assemblages surveyed south of Wiluna, there were some species that were obviously restricted to a particular vegetation assemblage (*i.e.* specialist; *e.g. Dasycercus cristicauda, Nephrurus laevissimus*) and there were others that were found in all vegetation assemblages (*i.e.* generalists) and at all sites (*e.g. Notomys alexis, Pseudomys desertor, Pseudomys hermannsburgensis*). There are species that were also found in each vegetation assemblage, but not in each site in each vegetation assemblage (Table 2), or their abundance varied appreciably among replicate sites. These are the species with patchy distributions, and who maybe locally abundant but go undetected in single site surveys for a vegetation assemblage.

Variability among replicate sites

If vegetation assemblages were homogenous and species were evenly dispersed across these habitats, then it probably would not matter where in each vegetation assemblage the sampling was undertaken and only one survey unit would be sufficient to detect all the species present presuming sufficient trapping effort was applied. However, in this survey the total number of shared species recorded among sites for each vegetation assemblage ranged from 47–75% (Table 4), indicating that species were not evenly distributed in each vegetation assemblage. These are species whose distributions are described earlier as patchy.

It is apparent from Tables 2, 3 and 4 that not only was there a significant difference in relative abundance of small vertebrates among vegetation assemblages, there were appreciable differences in measures of evenness and diversity among sites within vegetation assemblages. There were also significant differences among the number of individuals caught in each of the vertebrate families (see Table 2) among sites in each vegetation assemblage. Further, there was an appreciable difference in the number of individuals caught for some species among sites within a vegetation assemblage. For example, an extreme case of this was the number of *Ctenotus pantherinus* caught at the four mulga spinifex habitat sites and the number of *Ctenotus leonhardii* caught at all sites. This variability in the relative abundance of species is reflected in the low similarity scores among sites for each vegetation assemblage (Table 4).

It was anticipated that the surveyed sites would cluster within groups related to the vegetation assemblage to which they belong in the PCA. This is the case for the sites in the spinifex sand plain habitat and less so for the sites in the mulga and mulga spinifex vegetation assemblages. There was an obvious overlap in vertebrate fauna assemblages for the sand dune and chenopod vegetation assemblages, and a close affinity between one of the mulga spinifex and spinifex sand plain sites and a mulga site with a mulga spinifex site. For some vegetations assemblages, if only one site was surveyed, then the data could have appreciably misrepresented the fauna assemblage for the rest of that habitat.

Rare, range restricted and conservation significant species

Often of the focus of terrestrial fauna surveys undertaken to support EIAs is to identify the presence of rare, range restricted or conservation significant species. Rare is generally defined in terms of low abundance or small geographical range (Gaston 1997). Those with a small geographic range can be further subdivided into extent of occurrence, or the distance or area between the outer most limits of its occurrence, with the area of occupancy being the sites within its geographical range in which it is found (Gaston & Blackburn 2000). Some rare species can be abundant in areas that they occupy, but these are low in number or small in size. In addition, species can be deemed rare when they are difficult to trap, but are locally abundant. High levels of trapping are more likely to catch species that are both low in abundance and difficult to catch. Because of the trapping intensity in this survey, it is likely that we were catching species that were both low in abundance and difficult to catch (*e.g.* A. *laniger*, *D. cristicauda*, *S. hirtipes*, A. *picturata*). But because these species were caught in low numbers they contribute to appreciable differences in the fauna assemblage caught at each site in different vegetation assemblages. Our data indicate the need to collect large and multiple samples in each vegetation assemblage in order to record species that are rare or patchy in their abundance.

Trapping effort

In this survey the total number of trapped vertebrates in each vegetation assemblage generally exceeded the number of individuals caught by environmental consultants when undertaking fauna surveys to prepare EIAs (see Bamford Consulting Ecologists 2007; Biota Environmental Sciences 2005a, b; Ecologia Environmental Consultants 2004, 2006; Western Wildlife 2006; Outback Ecology Services 2006), yet the proportion of singletons caught in each vegetation assemblage was high (Table 3) and four of the five species accumulation curves for the combined data did not plateau indicating that only in the chenopod habitat were 90% of the species caught, suggesting that many of these other surveys would have failed to record numerous species. The EPA (2002) requires proponents of a development to ensure its biological surveys provide sufficient information to address both biodiversity conservation and ecological function values. We suggest that knowledge of both species richness and relative abundance are necessary to understand ecological function values of a habitat. To achieve this, an adequate number of individuals should be caught in each vegetation assemblage and sufficient replicate survey sites should be sampled. To detect the presence of species that have a low abundance over a large geographical distribution, large samples would be the preferred sampling protocol. To detect the presence of species that are locally abundant but have few areas of occupancy within their preferred habitat, then increasing the number of sampling sites would be the preferred protocol.

For a defined trapping effort (limited by time or resources), we have insufficient data to indicate whether it is better to increase the number of individuals caught at a few sites, or to increase the number of sampling sites but catch a lower number of individuals per site to increase the precision for the sample to represent the population. Read *et al.* (1988) compared trap sampling success for small mammals when traps were set out in a grid and along a line transect, and concluded that capture data were highly sensitive to sampling intensity when traps were set in a grid formation and were unlikely to represent true community diversity. However, this sensitivity in the grid formation varied appreciably based on trapping intensity. In contrast, capture data from traps set along a line transect were less influenced by intensity difference and provided a more accurate representation of true community diversity. Read *et al.* (1988) did not assess the protocol of multiple grids spread throughout a vegetation community, which may capture the benefits of both strategies.

In our study, all grids were uniformly spaced within each trapping site, with trap lines being approximately 20 m apart. It would therefore be interesting to compare capture data for mammals and reptiles from an equal number of traps set in a series of grids (*e.g.* 48 traps x 4 sites) with that in a linear transect (192 traps) through a uniform vegetation assemblage.

Conclusions

This investigation has demonstrated appreciable differences in both the composition and relative abundance in the trapped terrestrial vertebrate assemblage among replicate survey sites in each of five vegetation assemblages. Even when trapping yielded many more individuals than would normally be captured by environmental consultants in a vegetation assemblage, there was a high proportion of species that were singletons and doubletons and many species demonstrated a patchy distribution. These data support the Thompson *et al.* (2007) argument for trapping a much larger number of individuals in each vegetation assemblage than is the current practice and Greenwood and Robinson's (2006) argument for using multiple replicates in order to improve precision and representativeness in fauna surveys undertaken to prepare EIAs.

The WA Environmental Protection Authority's (2004) Guidance Statement No 56, *Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia* does not address the issue of spatial variability in fauna assemblages and therefore provides no guidance on how terrestrial fauna surveys should be designed to accommodate this issue. This omission needs to be addressed, given that this is the document that environmental consultants use in designing surveys for the purposes of preparing EIAs.

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